There are usually two mouth-pieces, interchangeable in position, one of which is used in speaking to the phonograph, and the other in giving out what this has to say. Each is specially adapted to the work it has to do. The metallic cylinder is rotated by means of an electric motor. The arm which carries the mouth-pieces is provided with a turning tool for smoothing the wax before this receives the record from the voice.

In Fig. 136, the phonograph is shown ready to talk. A conical speaking-trumpet is fixed upon the mouth-piece, so that the sound may be strengthened by co-vibration. The wax cylinder can be kept any length of time, and be made to speak out its message repeatedly. The phonograph reproduces so accurately the sounds it has received, that even the peculiarities which result from the special quality of the speaker's voice can be recognized.

12. The Human Ear is also an instrument for receiving sound vibrations, which affect the auditory nerve and produce sensation thus at the base of the brain. ("Hygienic Physiology," p. 216.)

(1.) Range of the Ear.—No definite limit can be assigned to the range through which musical sounds are perceptible. The highest limit has been roughly estimated to be about 38,000, and the lowest, 16, vibrations per second. When the number of impressions on the ear in each second is less than 15 or 16, we become able to perceive them separately. To be musical they must come fast enough to appear to coalesce. From 16 to 33,000 is about

eleven octaves. The capacity to hear the higher tones varies in different persons. A sound audible to one may be silence to another. Some ears can not distinguish the squeak of a bat or the chirp of a cricket, while others are acutely sensitive to these shrill sounds. Indeed, the auditory nerve seems generally more alive to the short, quick vibrations than to the long, slow ones. The whirr of a locust is much more noticeable than the sighing of the wind through the trees.*

(2.) The ability of the ear to detect and analyze sound is wonderful beyond comprehension. Sound-waves chase one another up and down through the air, superposed in entangled pulsations, yet a cylinder not larger than a quill conveys them to the ear, and each string of that wonderful harp selects its appropriate sound, and repeats the music to the soul. Though a thousand instruments be played at once, there is no confusion, but each is heard, and all blend in harmony.†

* To this, however, there are remarkable exceptions. The author knows a lady who is insensible to the higher tones of the voice, but acutely sensitive to the lower ones. Thus, on one occasion, being in a distant room, she did not notice the ringing of the bell announcing dinner, but heard the noise the bell made when returned to its place on the shelf.

† "Is not the ear the most perfect sense? A needle-woman will distinguish by the sound whether it is silk or cotton that is torn. Blind people recognize the age of persons by their voices. An architect, comparing the length of two lines separated from each other, if he estimate within $\frac{1}{30}$, we deem very accurate; but a musician would not be considered very precise who estimated within a quarter of a note ($128 \div 30 = 4$ nearly). In a large orchestra, the leader will distinguish each note of each instrument. We recognize an old-time friend by the sound of his voice, when the other senses utterly fail to recall him. The musician carries in his ear the idea of the musical key and every tone in the scale, though he is constantly hearing a multitude of sounds."

PRACTICAL QUESTIONS.

1. Why can not the rear of a long column of soldiers keep time to the music in front?
2. Three minutes elapse between the flash and the report of a thunderbolt; how far distant is it?
3. Five seconds expire between the flash and the report of a gun; what is its distance?
4. Suppose a speaking-tube should connect two villages ten miles apart; how long would it take the sound to travel?
5. The report of a pistol-shot was returned to the ear from the face of a cliff in four seconds; what was the distance?
6. What is the cause of the difference between the voice of man and woman? A base and a tenor voice?
7. What is the number of vibrations per second necessary to produce the fifth tone of the scale of C_3?
8. What is the length of each sound-wave in that tone when the temperature is at zero?
9. What is the number of vibrations in the fourth tone above C_2?
10. If a meteor were to explode at a height of 60 miles, would it be possible for its sound to be heard at sea-level?
11. A stone is let fall into a well, and in four seconds is heard to strike the bottom; how deep is the well?
12. What time would be required for a sound to travel five miles in the still water of a lake?
13. Does sound travel faster at the foot than at the top of a mountain?
14. Why is an echo weaker than the original sound?
15. Why is it so fatiguing to talk through a speaking-trumpet?
16. Why will the report of a cannon fired in a valley be heard on the top of a neighboring mountain, better than one fired on the top of a mountain will be heard in the valley?
17. Why do our footsteps in unfurnished dwellings sound so startlingly distinct?
18. Why do the echoes of an empty church disappear when the audience assemble?
19. What is the object of the sounding-board of a piano?
20. During some experiments, Tyndall found that a certain sound would pass through twelve folds of a dry silk handkerchief, but would be stopped by a single fold of a wet one. Explain.
21. What is the cause of the musical murmur often heard near telegraph lines?
22. Why will a variation in the quantity of water in a goblet, when this is made to sound, cause a difference in the tone produced by its vibration?
23. At what rate (in meters) will sound move through air at sea-level, the temperature being 20° C.?

SUMMARY.

SOUND is produced by vibrations. These are transmitted in waves through the air (60° F.) at sea-level at the rate of 1,120 ft. per second; through water four times, and through iron fifteen times as fast. In general, the velocity depends on the relation between the density and the elasticity of the medium; and the intensity is proportional to the square of the amplitude of the vibrations. Sound, like light, may be reflected and refracted to a focus. Echoes* are produced by the reflection of sound from smooth surfaces, not less than 112 ft. (about 33 meters) distant. Rapidly-repeated vibrations make a continuous sound; regular and rapid vibrations produce music; irregular ones cause a noise.

The pitch of a sound depends on the rapidity of the vibrations. The number of waves, and their consequent length in a given sound, is found by means of the siren. Unison is produced by identical wave-motions. Any number of sound-waves may traverse the air, as any number of water-waves may the surface of the sea, without losing their individuality. The motion of each molecule of air is the algebraic sum of the several motions it receives. Two systems of waves may therefore destroy or strengthen each other, according as they meet in oppo-

* Several acoustic phenomena have become of historical interest. (1.) Near Syracuse, Sicily, is a cave known as the Ear of Dionysius. A whisper at the farther end of the cavern is easily heard by a person at the entrance, though the distance is 200 ft. Tradition says that the Tyrant of Syracuse used this as a dungeon, and was thus enabled to listen to the conversation of his unfortunate prisoners. (2.) On the banks of the Nile, near Thebes, is a statue 47 ft. high, and extending 7 ft. below the ground. It is called the Vocal Memnon. Ancient writers tell us that about sunrise each morning, there issued from this gigantic monolith a musical sound resembling the breaking of a harp-string. It is now believed that this was produced by friction due to unequal expansion of different parts under the morning sun. (3.) Near Mount Sinai, in Arabia, remarkable sounds are produced by the sand falling down a declivity. The sand, which is very white, fine, and dry, lies at such an angle as to be easily set in motion by any cause, such as scraping away a little at the foot of the slope. The sand then rolls down with a sluggish motion, causing at first a low moan, that gradually swells to a roar like thunder, and finally dies away as the motion ceases.

site or in similar phases. Interference is the mutual weakening of two systems of waves which meet in opposite phases. Beats are the effect produced by two musical sounds of nearly the same pitch, which alternately interfere and coalesce. The vibrations of a cord produce a musical sound, which is re-enforced by a sounding-board. The rate of vibration and consequent pitch depends on the length, the tension, and the weight of the cord. A sounding body vibrates not only as a whole, but also in segments. Its vibration as a whole produces the fundamental tone, and the additional vibration in segments gives rise to the overtones. These together form either a complete or an interrupted harmonic series. The quality of the compound sound depends on the number, orders, relative intensities, and mode of combination of the overtones into which it can be resolved. The various notes in the musical scale are determined by fixed portions of the length of the cord. The music of a wind instrument is produced by vibrating columns of air. Resonance is a sympathetic vibration caused by one sonorous body acting on another, through a conducting medium, as seen in the resonance globe, etc. The voice is a reed instrument, with its vibrating cords and resonant cavity. The ear collects the sound-waves. It consists of the outer ear, the drum, and the labyrinth. The auditory nerve transmits to the brain the sensations produced in the ear by sound-waves.

HISTORICAL SKETCH.

The ancients knew that without air we should be plunged in eternal silence. "What is the sound of the voice," cried Seneca, "but the concussion of the air by the shock of the tongue? What sound could be heard except by the elasticity of the aërial fluid? The noise of horns, trumpets, hydraulic organs, is not that explained by the elastic force of the air?" Pythagoras, who lived in the sixth century before Christ, conceived that the celestial spheres are separated from each other by intervals corresponding with the relative lengths of strings arranged to produce harmonious tones. In his musical investigations he used a monochord, the original of the sonometer now employed by physicists, and wished that instrument to be engraved on his tomb. Pythagoras held that the musical intervals depend on mathematics; while his great rival, Aristoxenes, claimed that they should be tested by the ear alone. The theories of these two philosophers long divided the attention of the scientific world. The former considered the subject from the stand-point of Physics, the latter from that of Physiology.

Many centuries elapsed before any marked advance was made. Galileo called attention to the sonorous waves traversing the surface of a glass of water, when the glass is made to vibrate. He gave an accurate explanation of the phenomena of resonance, and referred to the fact that every pendulum has a fixed oscillation period of its own; that a succession of properly timed small impulses may throw a heavy pendulum into vibration, and that this may communicate vibration to a second pendulum of the same vibration period. Galileo also described the first experiment involving the direct determination of a vibration ratio for a known musical interval. He related that he was one day engaged in scraping a brass plate with an iron chisel, in order to remove some spots from it, and noticed that the passage of the chisel across the plate was sometimes accompanied by a shrill whistling sound. On looking closely at the plate, he found that the chisel had left on its surface a long row of indentations parallel to each other and separated by exactly equal intervals. This occurred only when a sound was heard. It was found that a rapid passage of it gave rise to a more acute sound, a slower passage to a graver sound, and that in the former case the indentations were closer together. After many trials, two sets of markings were obtained, which corresponded to a pair of tones making an exact fifth with each other. The indentations were 30 and 45, respectively, to a given length. Galileo's inference from this was exactly what we now accept as true.

The present century has witnessed a more complete demonstration of the laws of the vibrations of cords and the general principles of sound. In 1822, Arago, Gay-Lussac, and others decided the velocity of sound to be 337 *meters* at 10° C. Savart invented a toothed wheel by which he determined the number of vibrations in a given sound; Latour invented the siren, which gave still more accurate results; Colladon and Sturm, by a series of experiments at Lake Geneva, found the velocity of sound in water; Helmholtz made known the laws of harmonics; Lissajous, by means of a mirror attached to the vibrating body, threw the vibrations on a screen in a series of curves, and so rendered them visible; while Tyndall has investigated the causes modifying the propagation of sound, as acoustic clouds, fogs, etc., and popularized the whole subject of acoustics.

VII.

ON LIGHT.

THE sunbeam comes to the earth as simply motion of ether-waves, yet it is the grand source of beauty and power. Its heat, light, and chemical energy work every-where the wonder of life and motion. In the growing plant, the burning coal, the flying bird, the glaring lightning, the blooming flower, the rushing engine, the roaring cataract, the pattering rain—we see only varied manifestations of this one protean energy which we receive from the sun.